Preventive to Predictive

The future of Transformer Oil Testing

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Preventive to Predictive, the Future of Transformer Oil Testing

Transformers form a critical part of our electrical world. Without them we would not be able to transmit and distribute electricity generated at remote power stations. Over time transformers fail which can be costly not only to the utility or owner of the transformer but the consumer as well. Oil is used as an insulator and a coolant in transformers and by monitoring its condition the transformer's overall health is determined. This paper will discuss the importance of routine testing of transformer oil and what role it plays in a preventive maintenance program.

Living in Canada or the US we have been educated in the importance of routine testing of expensive equipment. Even in our personal lives we make sure that we routinely change the oil in our cars. If we didn't the engine would seize and we wouldn't be able to go anywhere. In the past not much was known about the interaction of the components within a transformer. Electrical engineers understood the need for the different components but not what happens when something goes wrong or fails. Early designers of transformers thought that since there were no moving parts, transformers would never fail. Unfortunately this is not so, transformers do develop problems and all will eventually fail in one-way or another. In developing countries routine transformer maintenance is just starting to be observed. Many large power generation projects are being constructed or have recently been commissioned. With the increasing population and demand for more power both the developed and developing countries must have a continuous supply of power. By performing routine oil tests much information can be learned from transformers in the same way that a doctor takes a blood sample. The information acquired can be used to prevent unscheduled outages, production losses and transformer failures.

The oil inside a transformer has two important properties; the first being that it is a good insulator and the second is as a coolant. It is one accessible portion of the transformer since most components are contained within the main tank. Internal inspections are not necessary when a transformer is functioning properly. And an inspection would do more harm than good, as it would allow air and moisture to be absorbed by the insulation system. Air and moisture are two enemies of transformers. By taking an oil sample we are able to observe the status of the equipment without exposing it to these detrimental elements.

Transformers are greater than 95% efficient and the losses are minimal, however one of the losses is heat. The oil cools the transformer and with the help of the radiators it will circulate throughout the tank. Radiators and fans are installed to accelerate this process. The oil, therefore, comes in contact will all areas in the transformer and it will tell us of developing problems inside the tank. Samples of the oil must then be obtained for it to tell us of these problems. Sampling of the transformer oil is not a difficult procedure but it must be done properly. The analysis of the oil is only as good as the sample obtained. If the sample is poor the analysis will not reflect the true nature of the equipment.

Following is an explanation of the proper way to take oil samples for dissolved gas analysis (DGA) from a transformer. In reading this procedure an auxiliary-sampling valve is not only mentioned but can be seen in the drawings. Bubble free samples can be obtained without the use of this auxiliary valve if one is lacking. Jar or bottle samples should be taken with the same care of flushing and rinsing.

The methods outlined here are all based on the use of a single sampling device, which can be used to take, either oil or gas samples. The sampling device consists of a precision ground 30 cc glass syringe terminated with a Luer-Lok fitting to which is attached a plastic three way valve. This valve, although removable, is to be regarded as an integral part of the sampling device and any subsequent references to the syringe imply the presence of this valve. A second identical valve, which does not stay with the syringe, is used when taking oil samples. This second valve will be referred to as the auxiliary valve.

Before sampling the syringe must be either flushed with new transformer oil or pumped vigorously several times with the valve open to eliminate any residual fault gas from the previous sample. The syringe should be examined for the absence of dirt and checked to ensure that the piston slides smoothly. The syringe must have a small amount of oil present at all times to ensure a proper seal between the piston and the barrel and to ensure that the piston slides smoothly. By flushing the syringe with oil from the transformer, the oil originally found in the syringe will be eliminated.

For taking oil samples, an adapter must be made which can be fitted to the transformer valve and which will accept the tapered inlet of the auxiliary sampling valve. One possibility, shown in Fig. 1, is to epoxy or solder a female Luer hub (cut down from a 15 gauge needle) into a suitably sized hole drilled into the transformer valve plug. Alternatively, a straight 5/32-inch diameter hole drilled in the transformer valve plug will yield an adequate press fit for the auxiliary valve.

Note, however, that a straight hole can score and deform the plastic valve and hence the syringe valve should not be plugged into a straight hole nor should the syringe and auxiliary valves be interchanged. One role of the auxiliary valve is to protect the syringe valve so that it will stay in good condition. The syringe valve must be kept in good condition since the laboratory that analyzes the sample will attach it to their equipment

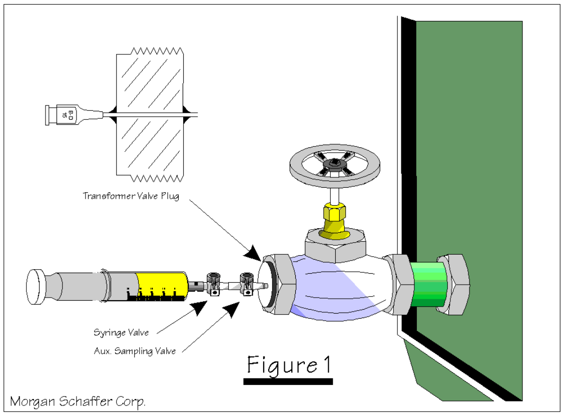

Figure 1

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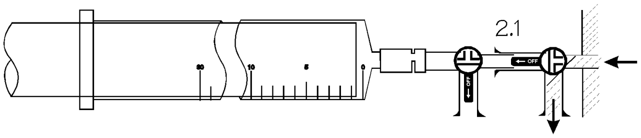
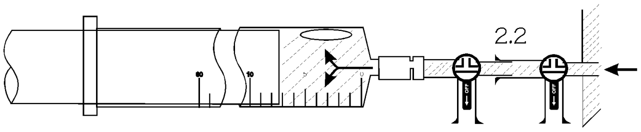
A satisfactory technique for taking bubble-free oil samples is shown in Figs. 1 and 2. The flushing ports of the valves are shown horizontal in Fig. 1 but in practice it is better if they are directed downward to facilitate collection of the waste oil. (Note: the handles of the plastic valves point to the closed port leaving the other two ports in open communication.)

The technique described below requires the oil to be under a slight positive pressure (0.2 psig or greater). A continuous flow is maintained throughout the entire procedure.

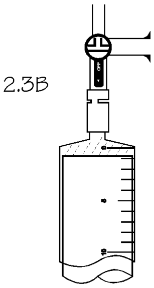
a) Attach the adapter plug to the transformer valve, then, with its handle in the flush position, plug in the auxiliary valve and allow oil to flush until all trapped air is eliminated. Adjust the oil flow to a suitable rate and then attach the syringe with its valve in the fill position. (Fig. 2.1).

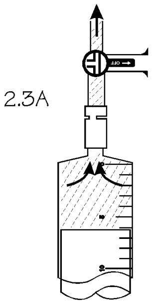


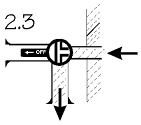
b) Turn the auxiliary valve to the fill position and allow about 10 cc of oil to enter the syringe (Fig. 2.2).



Return the auxiliary valve to its flush position and separate the syringe (Fig. 2.3).

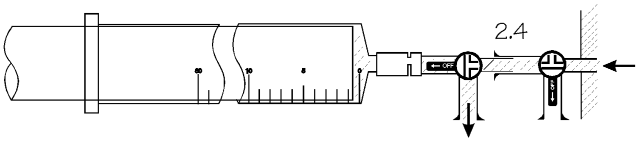


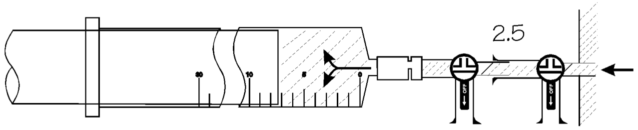


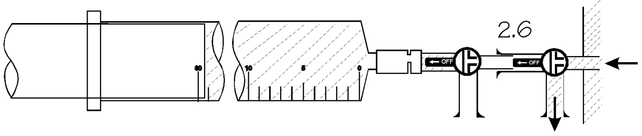


c) With the syringe vertical, eject any air bubbles (Fig. 2.3A) and then depress the piston to the zero mark and close the syringe valve (Fig. 2.3B)

d) The syringe, bubble free and with its dead volume filled with oil, is then re-attached to the auxiliary sampling valve. The auxiliary valve is then turned to the fill position so that oil now flows from the flushing port of the syringe valve (Fig. 2.4).







e) Turn the syringe valve to the fill position and allow oil pressure to push the piston back until the syringe contains approximately 26 cc of oil (Fig. 2.5). Note: if it can be avoided, do not pull the piston manually since this can result in atmospheric leakage and bubble formation. Do not fill the syringe to more than 27 cc to ensure an adequate seal along the piston.

f) Return the syringe and auxiliary valves to their flush positions, separate the syringe and close the transformer valve.

Note: *Bubbles may form in the syringe subsequent to sampling because of the different temperature and pressure environment but, provided the sample was bubble free initially, this will not affect the subsequent analysis. No attempt should be made to remove such bubbles.*

Once the oil has been sampled from the transformer analyses can then be performed. The oil itself is important and must be maintained in optimal condition to fulfill its function. A large number of tests are available but there are only 4 or 5 that provide the information needed to evaluate the condition of the oil. Should one or more properties of the oil fall below an accepted norm disastrous events can occur. As stated earlier the oil is used not only as a coolant but as an insulator as well. Being an insulator it must be able to withstand a large amount of electrical stress without failure. This is determined by its dielectric strength. Should an oil's dielectric strength fall below a certain level a flashover can occur. Low breakdown voltages indicate that an oil is contaminated with conductive particles and or free water. Moisture in solution will not be detected in this test as good results can be obtained with a dissolved water content greater than 50 ppm. There are two ASTM (American Society for Testing and Materials) methods for measuring dielectric strength, the first is D-877 using flat disk electrodes and the second is D-1816 that utilizes round or VDE electrodes. The latter test is highly sensitive to moisture and other contaminants. This test is used more as an acceptance and qualification test, whereas D-877 is used for oil that is in service. Acceptable limits for dielectric strength can be found in Table 1.

Two tests that help determine oil quality are interfacial tension and acidity or neutralization number. These measure the degree of deterioration or level of oxidation of an oil. Within a transformer, oil is subjected to high temperatures in the presence of oxygen. When the oil becomes oxidized it becomes more acidic. The increased acidity is caused by the oxidation byproducts: alcohols, aldehydes, ketones, esters, and acids. These can be grouped together and called polar compounds. The polar compounds lower the interfacial tension. Therefore, as the acidity of the oil increases due to oxidation the interfacial tension will decrease. Recommended limits for interfacial tension and acidity can be found in Table 1.

Water is an enemy of the solid insulation within a transformer. Most (99%) of the moisture in transformers is found in the solid insulation. By measuring the water content in the oil it can be determined how much water is in the paper. The water harms the paper and will affect permanent damage. When combined with the heat that is generated in a transformer the water will lower the tensile strength of the paper. Precautions must be taken when sampling oil for moisture content, as it is very easy to introduce water into the samples. Dissolved water acts like a dissolved gas therefore the samples must be taken in the same way. The sampling procedures mentioned above should be used for moisture content and the samples should be taken in syringes.

Water can come from a number of sources. There could be a leak in a gasket, it could get in through a depleted silica gel breather, it will get in whenever there is an internal inspection and it is generated by the normal deterioration of the oil and the paper. By insuring that water is kept to a minimum, the life of the transformer can be maximized. Recommended limits for water content can be found in Table 1.

Table 1

ASTM Test Method	Limit for new oil	Limit for service aged oil
Dielectric Strength ASTM D-877	30 kV minimum	25 kV minimum
Dielectric Strength ASTM D-1816 0.040 inch gap	28 kV minimum	
Dielectric Strength ASTM D-1816 0.080 inch gap	56 kV minimum	35 kV minimum
Interfacial Tension ASTM D-971	40 dynes/cm minimum	18 dynes/cm minimum
Neutralization Number ASTM D-974	0.03 mg KOH/g maximum	0.2 mg KOH/g maximum
Water Content ASTM D-1533	35 ppm maximum	35 ppm maximum

There are many other tests that can be performed on insulating oil but these four tests along with density; colour and a visual inspection will give a very good picture of the quality of the oil.

The main goal of testing a transformer's oil is not just to determine the quality of the oil but to evaluate the operating status of the equipment. There are only two oil tests that do this and they are dissolved gas analysis and furan analysis. The oil is continuously circulating throughout transformers. The oil is a hydrocarbon, meaning it is made up primarily of a long chain of carbon and hydrogen atoms. When the oil comes in contact with a fault it will start to break down. Dissolved gas analysis is the process of extracting and measuring these byproducts. The byproducts come in the form of low molecular weight hydrocarbons and are the symptom of the problem. As can be seen in Figure 3, the oil is broken down into different combinations of gases depending on the fault type.

The basis of fault interpretation comes from looking at the generated gases. As Figure 3 demonstrates each of the three fault types, corona, thermal and arcing produces different combination of gases. By measuring the quantity of each gas and comparing its amount to the other gas levels, the fault type can be determined. Recommended levels for the fault gases can be found in Table 2. The levels shown are from Dornenburg and Strittmatter and the second set from the US Bureau of Reclamation. There are many recommended levels and Table 2 is representative of the levels in many interpretation schemes. The severity of the fault is determined by the gas generation rate. If the gases are being produced at a slow rate, the fault is not as severe as when the gases are produced at a high rate. Historical data is very important when considering the operating status of transformers. One cannot determine if there is a fault or how severe it is with one set of results. A trend of the results must be performed to properly evaluate the equipment.

There are many interpretation schemes and even computer programs that can diagnose DGA results. This paper will not delve into the different methods, as it would take too much space. One note however is that almost all the methods perform a ratio analysis of the gases and by comparing the gases the type of fault is determined.

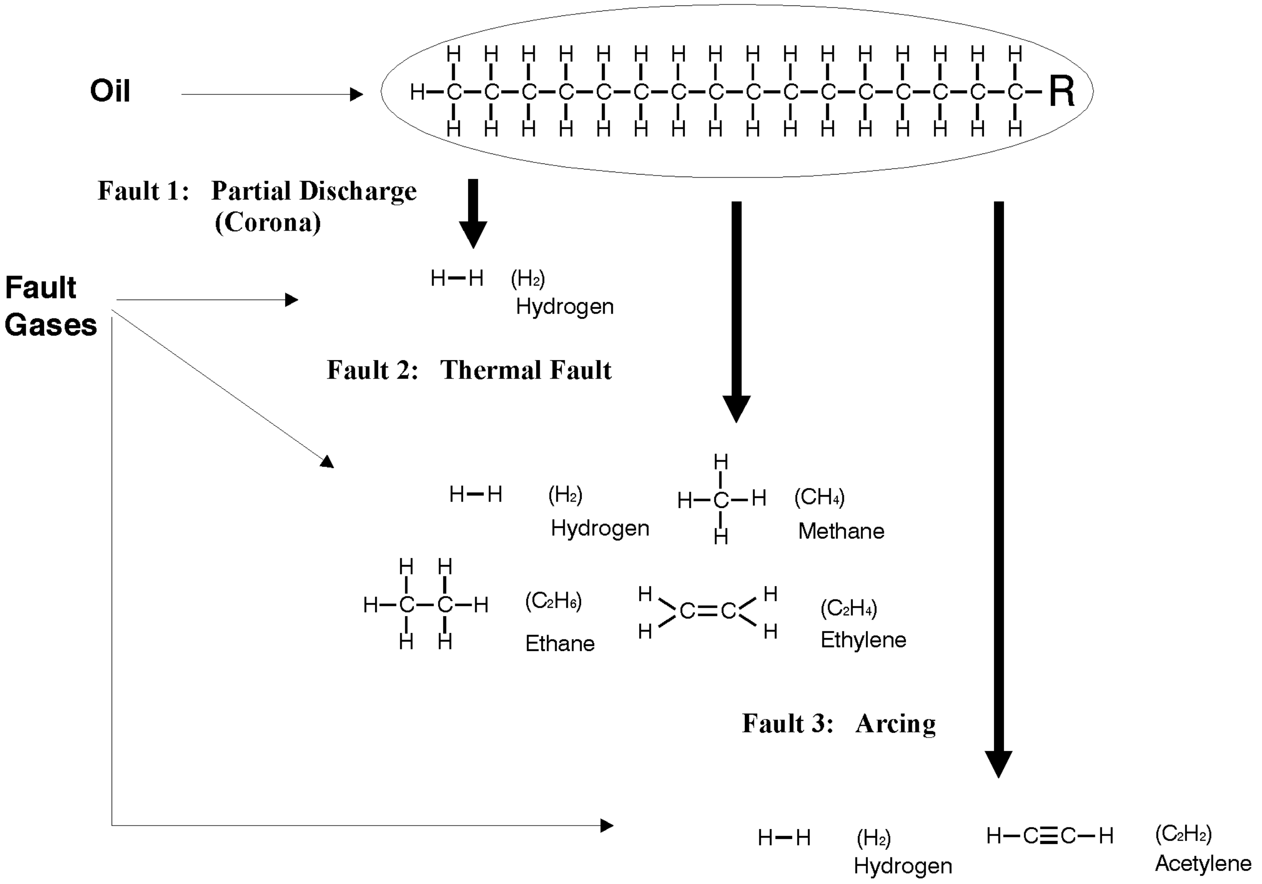
Table 2

Recommended Fault Gas Levels in Parts per Million (ppm)

Fault Gas	Dornenburg and Strittmatter	US Bureau of Reclamation
Hydrogen (H2)	200	500
Methane (CH4)	50	125
Ethylene (C2H4)	80	175
Ethane (C2H6)	35	75
Acetylene (C2H2)	5	15
Carbon Monoxide (CO)	500	750
Carbon Dioxide (CO2)	6,000	11,000

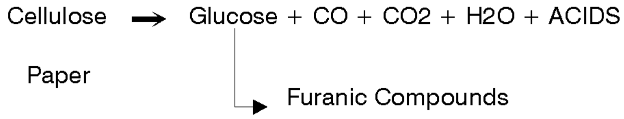
Figure 3

Oil breakdown products



The other test that is used to determine the operating status of transformers is furan analysis. Furans are produced from the breakdown of the solid insulation within transformers. Figure 4 shows the breakdown of the cellulose or paper in a transformer. As can be seen CO and CO2 are generated. But it has been noted that these gases can be produced in transformers at elevated levels even when there is no paper degradation. This could be due to some of the components used in the manufacturing. It has been shown that glucose is formed only when the paper degrades. The glucose then converts into furans, which can be measured.

Figure 4
Paper degradation products



The furanic compounds will only form when the paper is overheated. Therefore if they are present, the paper in the transformer has been subjected to elevated temperatures. Furans are found at very low levels but if a transformer shows levels greater than 250 parts per billion more investigation may be needed. If they are higher than 1000 ppb then the paper has at some point in time has been damaged.

The tests mentioned in this paper form a part of a preventive maintenance program. Routine substation and transformer maintenance is performed usually every 6 to 12 months. This maintenance consists of inspections and cleaning of various components of the substation. Electrical tests are performed and oil samples are taken from the transformers. The practice of a preventive maintenance program is designed to perform inspections and replace equipment before it fails which may inadvertently initiate a failure. By replacing a part that is operating properly or performing an invasive inspection that may accelerate the aging of a component, the life of a component can be reduced. In the case of power transformers much information can be gleaned by analyzing the oil. But if this procedure is performed only once every one to two years, what prevents the failure of the equipment between the sampling periods? By increasing sampling frequency more data can be analyzed and failures can not only be prevented but also predicted much earlier. This is the focus of a transformer predictive maintenance program. On-site analyzers can be used to screen oil filled equipment for the generation of fault gases between routine samplings. By verifying the level of one key gas, equipment can be filtered out that may be developing problems whereas others that are operating properly can be left alone until the next scheduled maintenance. As can be seen in Fig. 3 one gas is produced in all transformer faults and this gas is hydrogen. Analyzers are available now that test for this one specific gas. An example of this type of analyzer is the PHA-1000.

Portable Hydrogen Analyzer PHA-1000

It is a portable hydrogen analyzer that is easy to use and the results are given in minutes. In a case where many transformers are located close together, all can be checked for hydrogen concentration by a technician that does not need to be highly skilled. If the transformers are all in close proximity 30 to 40 can be screened for hydrogen in one day. This way the transformer owner has some control over the maintenance practices. By identifying problematic equipment before they escalate into catastrophic failures, outages, production losses and costly repairs can be avoided. Once identified more extensive testing can then be done to confirm the type and severity of the fault.

Screening tools are useful but in some situations complete on-site DGA is the only way to go. If it is difficult to get samples to a central lab for analysis or if the time it takes to get results is unacceptable, having an instrument that performs a complete DGA on-site could make decision-making much easier. By having an on-site analyzer like the TFGA-P200, results are obtained in minutes without sending samples to a lab for analysis. Portable analyzers like the TFGA-P200 allow the owner of the transformer to increase sampling frequency at virtually zero extra cost.

With easy to operate software a technician that is competent with computers can be trained in a very short period. When the results are in hand just minutes after a transformer has tripped a decision can be made of whether to reenergize or to shutdown and perform an inspection. Complimented with diagnostic software a true picture of the operating status of the transformer is obtained. Using this type of instrument, sampling frequency can be increased. By doing so faulty equipment can be flagged for more testing and eventual inspection. The more data points available, better decisions are made.

Portable Fault Gas Analyzer TFGA-P200

In critical situations where transformers must be watched constantly an on-line monitor would provide the security and insurance needed to warn of any developing problems. These monitors continuously measure and record gas levels found in transformers. They will detect faults sooner than the Buchholz relay. Once the Buchholz has tripped it is usually too late and the damage has been done.

One such monitor the AMS-500Plus/Calisto measures the dissolved hydrogen and dissolved water found in transformer oil. Again going back to Fig. 3 hydrogen is produced in all faults, by monitoring its concentration faults can be uncovered in their infancy. These devices also store the data so when an alarm sounds the data can be downloaded to determine the rate at which the gas is being generated. This in turn tells us the severity of the fault. On-line monitors are predictive maintenance tools as they warn of upcoming problems. They provide a means of insurance between routine preventive maintenance practices. There have been many cases where the installation of on-line monitors has saved transformers from catastrophic failures. This type of monitor will detect the fault in its early stage where a shutdown can be scheduled as opposed to the transformer failure causing a shutdown.

Calisto dissolved hydrogen
and water monitor

The oil in a transformer performs a very important role. It is the blood of the transformer and as in humans it must be kept in optimal condition. By following a maintenance program, the benefits highly outweigh the costs. The costs per transformer can be as little as two hundred dollars per year. The failure of a transformer can easily reach one hundred thousand for large units. Don’t be left in the dark, follow a maintenance program that fits your budget. It is the best insurance for your transformers.